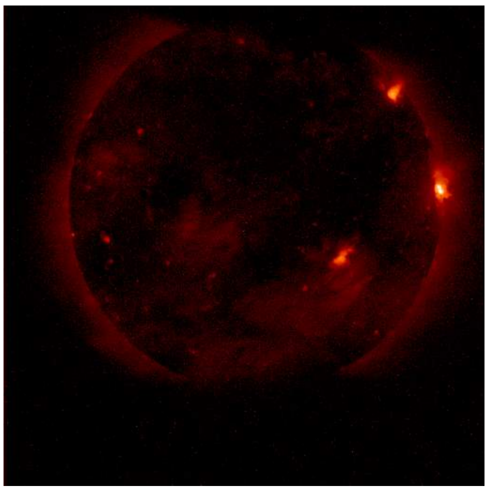
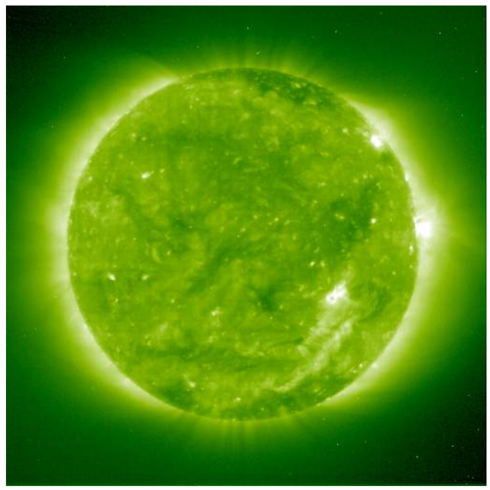
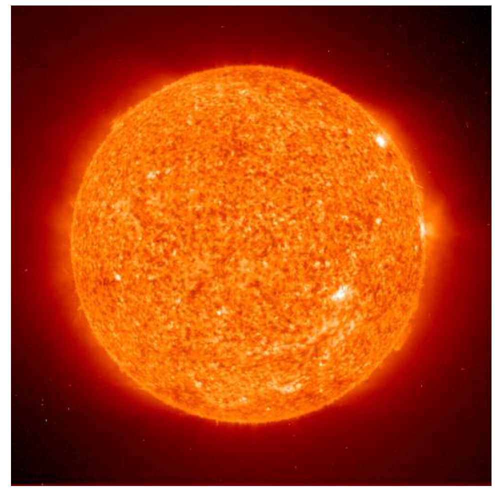
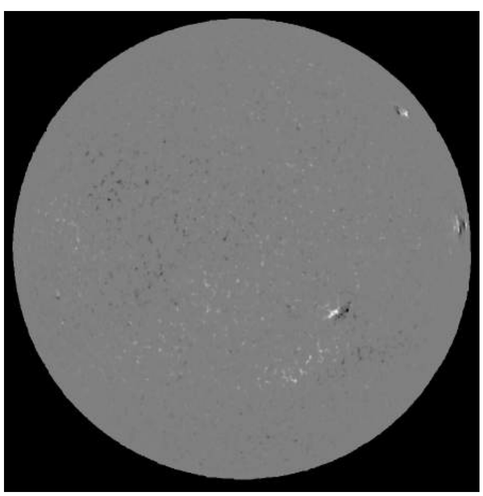
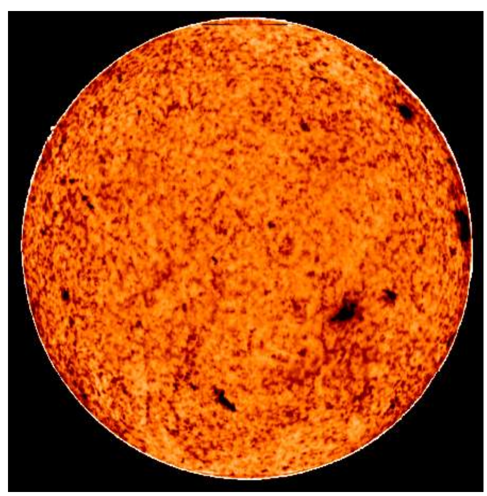
How Astronomers Use Spectra to Learn About the Sun and Other Stars

by Dr. Jeffrey W. Brosius

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Goddard Space Flight Center
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About the Cover: The cover shows five different pictures of the same star: our Sun. All of the pictures were taken either late on February 6 or early on February 7, 1997. Because your eyes cannot see the kinds of light that were used to take four of them, the pictures are all shown in false color. The figure in the upper left is an X-ray picture. It was taken with the Soft X-ray Telescope (known as "SXT") aboard the Japanese *Yohkoh* spacecraft. The figures in the upper middle and upper right are ultraviolet pictures, and they show what the Sun looked like at two different ultraviolet wavelengths. They were taken with the Extreme-ultraviolet Imaging Telescope ("EIT") aboard the Solar and Heliospheric Observatory ("SOHO") spacecraft. This spacecraft was built as a joint effort between the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The figure in the lower left shows the Sun's magnetic field. This image was derived from visible light observed at the U.S. National Solar Observatory at Kitt Peak, Arizona. The figure in the lower right shows an infrared picture of the Sun. It too was taken at Kitt Peak. Can you find any differences among all the pictures? Keep in mind that your eyes cannot see X-ray light, ultraviolet light, or infrared light, but astronomers must observe all of the different kinds of light that come from the Sun in order to understand how the Sun works, and how the Sun affects the Earth. Pictures like the ones shown on the cover provide clues to help solve some of the Sun's mysteries. However, additional information, such as that provided by *spectra*, is also needed. This booklet describes how astronomers use spectra to learn about the Sun and other stars. Interested readers will find a wealth of additional information about SOHO and other NASA space missions by visiting the Goddard Space Flight Center homepage on the World Wide Web at "http://www.gsfc.nasa.gov/GSFC_homepage.html", or by visiting the SOHO homepage at "http://sohowww.nascom.nasa.gov/". A copy of the following document, along with some interactive activities and lots of information about the Sun and sounding rockets, can be found on the SERTS homepage at "http://orpheus.nascom.nasa.gov/serts/".

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by Dr. Jeffrey W. Brosius
Institute for Astrophysics and Computational Sciences
The Catholic University of America
Washington, DC 20064

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1 How do astronomers get information about the Sun and stars?

Astronomers unravel mysteries about objects out in space, far from Earth: the Sun; the Moon; planets; comets and asteroids; normal stars, stars being born, dying stars, exploding stars; black holes; galaxies of stars; and strange, hyperactive galaxies from the dawn of time. Astronomers have learned a lot about these objects, and every day discover new, exciting things. How do they do it? How do astronomers learn so much about objects which are either too far away or so dangerous to visit that they have never been explored directly by people or by man-made spacecraft?

The Moon, of course, is close enough that astronauts have gone there safely and returned to Earth with samples of rocks and soil. This means that pieces of the Moon can be touched and studied close-up. The planets in our solar system are much farther away than the Moon, and none of them has yet been visited by astronauts; however, all of the planets except Pluto have been landed on, or orbited, or flown near, by spacecraft built on Earth. This means that scientists have been able to get a fairly close look at the planets; in some cases, they use robots to study samples of soil, rocks, and atmosphere. Even Halley's Comet, a periodic guest from the outer reaches of the solar system, was approached closely by several spacecraft from Earth during its last visit. Perhaps astronauts will visit Mars early in the 21st century.

The Sun, however, is so hot that nothing can get very close to it without burning up. This is what happens to "Sun-grazing" comets, which disappear in the intense heat when they approach the Sun too closely. The question, then, is this: If astronomers can neither touch the Sun themselves nor send spacecraft there to touch it for them, how can they learn anything about the Sun? A related question is: How do astronomers discover secrets about other stars and other objects in space which are so far away that no spacecraft from Earth has ever been there?

2 By the light that the Sun and stars send to us.

To get information about objects out in space far away from Earth, astronomers need something from those objects that carries information to the Earth. What is that something? What do things out in space send to Earth to tell us about themselves?

To answer these questions, think about how you know that the Sun, stars, and other objects in space exist. Imagine yourself looking toward the Sun on a clear day; your eyes see so much sunlight that they can actually hurt. (Never look directly at the Sun. The light is so bright that it can permanently damage your eyes.) Now imagine yourself looking up on a clear night far from city lights; your eyes see starlight from thousands of twinkling stars. How do you know that the Sun and stars are there? The answer, of course, is by the light that they send us!

Light carries a lot of information. It tells us not only that various objects exist and how bright they are, but also about their composition (what elements the objects are made of), temperatures, densities, motions, and magnetic fields. With the proper tools, astronomers can dig information like buried treasure out of the light that they receive. Several of these tools will be described below, and the reader can use some of them to dig information out of real observations of the Sun obtained with one of NASA's rocket experiments.

3 The electromagnetic spectrum: a collection of waves with different wavelengths.

Light can be described as waves that travel through space, like the ripples that travel across a pond after a stone has been dropped into the water. For both light and pond ripples, the *wavelength* of the waves is the distance between wave peaks. (See Figure 1.) The light that your eyes can see is known as *visible light*. Different wavelengths of visible light are seen as different colors by your eyes. From longer to shorter wavelength, the various colors that your eyes can see are red, orange, yellow, green, blue, and violet. Ordinary white light is a mix of all colors, or, in other words, a mix of light at all visible wavelengths. When a rainbow appears in the sky after a storm, you see ordinary white sunlight that has been separated into its individual colors by tiny droplets of water in the air. Next time you see a rainbow, notice that the colors appear in the order listed above.

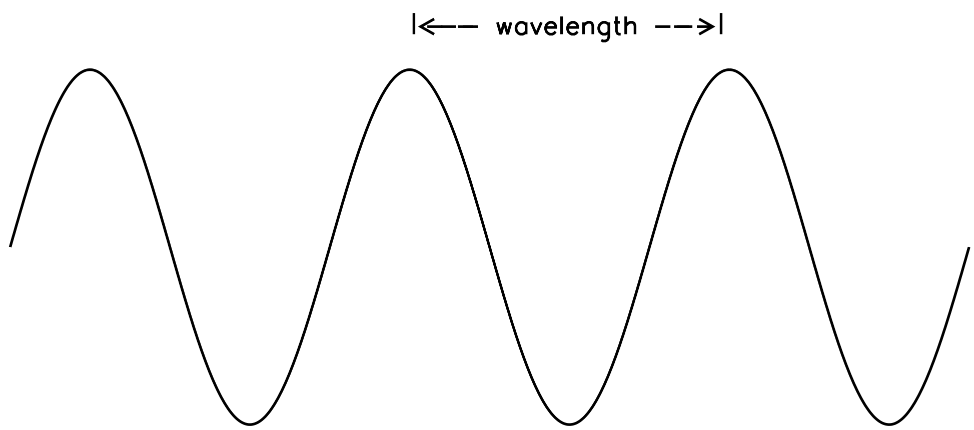


Figure 1: *Wavelength* is the distance between wave peaks.

But the Sun and stars send us more than just visible light: they send invisible light as well. Invisible light has either longer wavelengths (like infrared [pronounced in-fra-red], microwave, and radio waves) or shorter wavelengths (like ultraviolet, X-ray, and gamma rays) than the visible light that we can see with our eyes. The technical term for all these forms of light is *electromagnetic radiation*. When placed side by side in order of increasing or decreasing wavelength, the different forms of light make up the *electromagnetic spectrum*. A rainbow, which is a *visible light spectrum*, is just one small part of the whole electromagnetic spectrum. (See Figure 2.) Arranged in order of increasing wavelength, the electromagnetic spectrum consists of gamma ray, X-ray, ultraviolet, visible, infrared, microwave, and radio waves. To gather as much as possible of the information sent out by the Sun and stars, astronomers need to collect light from many different wavelengths over a wide range of the electromagnetic spectrum. Earth's atmosphere, however, causes some big problems with this.

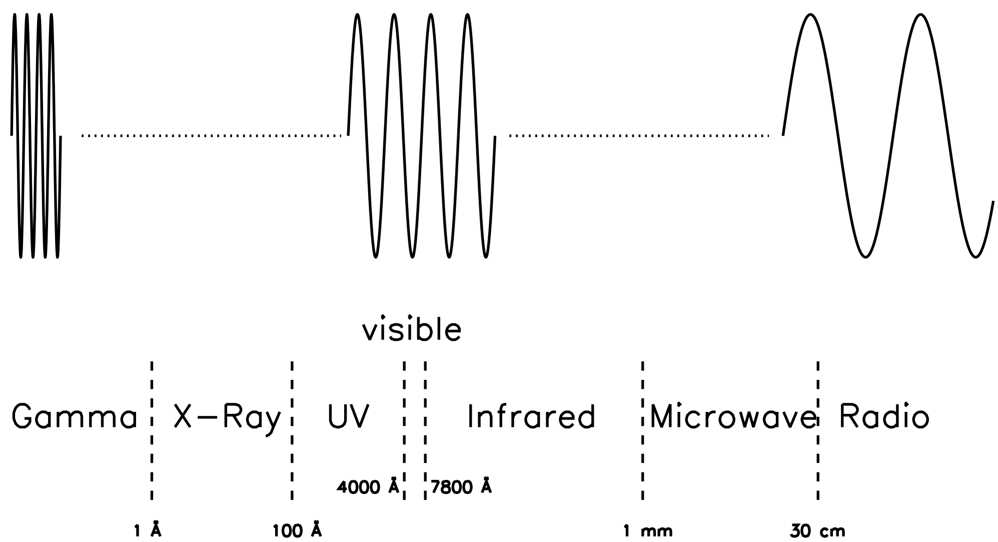


Figure 2: The *electromagnetic spectrum* contains light waves of all different wavelengths. The symbol "Å" means "Angstrom", a unit of length often used to describe wavelengths of light. One Angstrom is one ten-billionth, or 10^{-10}, of a meter. Notice that the portion of the electromagnetic spectrum that is visible to the human eye is fairly small.

Earth's atmosphere absorbs most of the invisible light from the Sun and stars over much of the electromagnetic spectrum. This is good for life on Earth, since exposure to too much ultraviolet, X-ray, and gamma ray radiation would be harmful. However, this is bad for astronomers since information carried by light at these wavelengths cannot reach the ground. So astronomers send special telescopes above Earth's protective atmosphere to observe the Sun and stars at wavelengths which are absorbed by air. Depending on the wavelength range that astronomers wish to study and the time period needed to study it, these special telescopes can be carried into the highest parts of the atmosphere by balloons, or sent above the atmosphere for a short period of time (about 10 minutes) by small rockets known as "sounding rockets," or launched into orbit around Earth by large rockets. No single telescope can detect radiation over the entire electromagnetic spectrum: different equipment must be designed and built for different wavelength ranges.

4 Some tools for digging information out of solar and stellar spectra.

When light from the Sun or stars is displayed according to wavelength, the result is said to be a *spectrum.* More than one spectrum are called *spectra* (not spectrums). Astronomers get a lot of information about the Sun and stars from solar (which means "of the Sun") and stellar (which means "of the stars") spectra.

Like everything on Earth, the Sun, stars, and other objects out in space are made of atoms. An atom is the smallest unit which can be identified as any particular element (like hydrogen, helium, carbon, nitrogen, oxygen, iron, and so on). Since there are about 100 different elements, there are also about 100 different kinds of atoms.

The center of an atom is its nucleus, which is a collection of protons and neutrons. Electrons surround the nucleus. An atom is neutral if it has as many electrons outside the nucleus as protons in the nucleus. But sometimes an atom loses one or more of its electrons. This happens when the atom is bumped by something with enough energy to kick the electrons out. In the outer atmospheres of the Sun and stars, which are quite hot, the atoms all move fast and get bumped very hard. This causes most of the atoms to lose some of their electrons. Atoms which have had one or more of their electrons removed are called *ions.* The higher the temperature, the more electrons are missing from the ions. If an ion moves to a cooler place, nearby electrons will be captured again. This means that each different kind of ion can survive only in places where the temperature is just right. (The "missing" electrons do not disappear: they are free to roam around and bump into atoms, ions, and other electrons.)

Astronomers rely upon *atomic physics* in order to dig information out of solar and stellar spectra. Atomic physics is the branch of science that deals with atoms, ions, and the light that comes from atoms and ions. Each different type of atom and each different type of ion emit light waves at a combination of wavelengths that are special to that particular type of atom or ion. In other words, the wavelengths of the light waves that are sent out by one kind of atom or ion are different from the wavelengths of light waves that are sent out by another kind of atom or ion. These light waves have become known as *emission lines* because light at these particular wavelengths looked like many straight lines in a spectrum when astronomers first obtained them. (See Figure 3.)

Each different type of atom and each different type of ion emit their own special, unique set of emission lines. Astronomers use these emission lines to identify the atoms or ions that send out light from the Sun and stars. This is similar to the way a detective uses fingerprints to determine whose hands have touched an object. Once astronomers have determined what ions are present on the Sun and stars, they know immediately what elements are there. (Remember that ions are just atoms of a given element that have lost one or more of their electrons.) Furthermore, astronomers know how hot the Sun and stars are because each different type of ion is found only at a certain temperature.

In addition to providing information about (1) the composition of the Sun and stars and (2) temperatures on the Sun and stars, emission lines also provide information about (3) densities (the number of atoms or ions in a given volume), (4) motions, and (5) magnetic fields, as well as other quantities. For example, astronomers can sometimes measure densities by comparing how bright some emission lines are to others. Astronomers can also measure motions on the Sun and stars by measuring changes in the wavelengths of emission lines, or by the shapes of emission lines in the spectra. Motions can be measured because of the *Doppler effect*, in which the wavelength of waves from an emitter are shortened when the source approaches, and lengthened when the source moves away. (For example, a car horn's pitch sounds higher when the car is coming than it does when the car is going away.) Finally, magnetic fields on the Sun and on some stars can be measured because the effects of such fields on electromagnetic radiation are fairly well known.

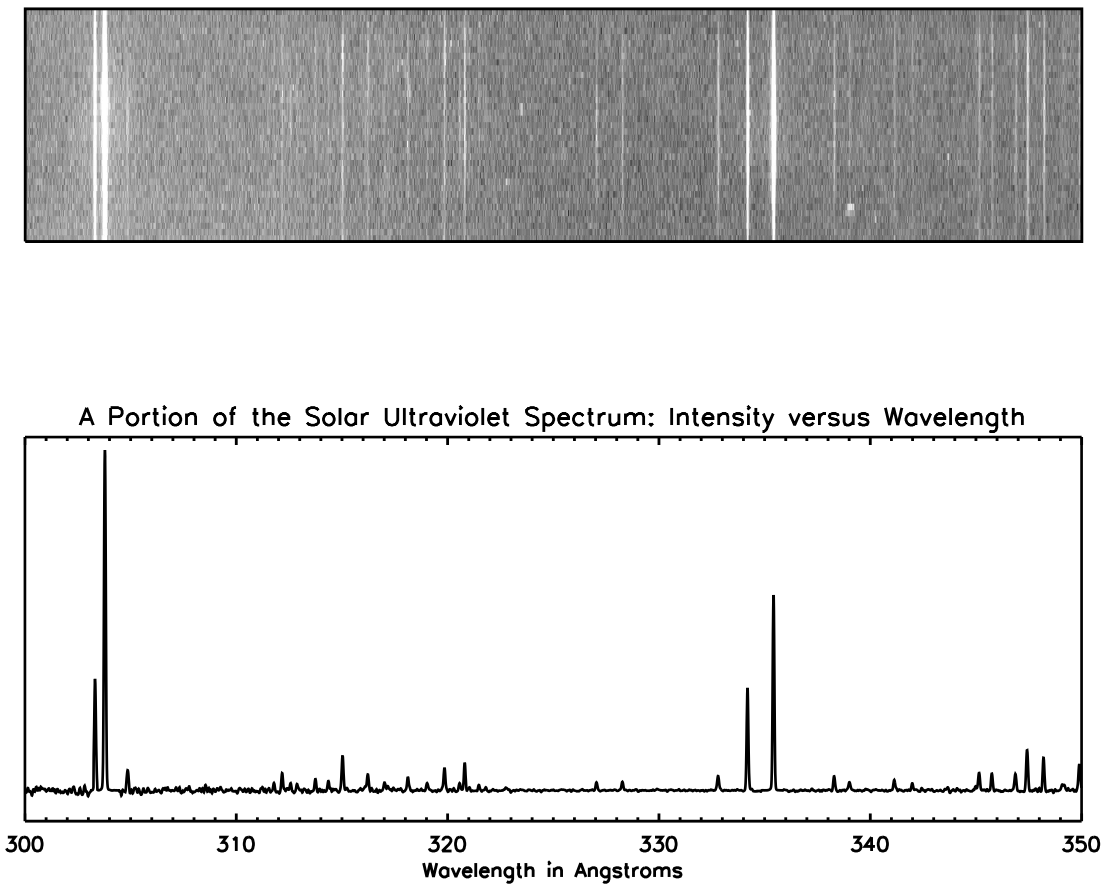


Figure 3: The top frame shows part of a solar ultraviolet emission line spectrum obtained with NASA's Solar Extreme-ultraviolet Rocket Telescope and Spectrograph (known as "SERTS") sounding rocket experiment on August 17, 1993. Wavelength increases from 300 Å on the far left to 350 Å on the far right. Clearly, some lines are very bright while others are very faint. The graph in the bottom frame is a different way to show how bright the lines are at each different wavelength. Brightness (also called "intensity") is in the vertical direction, and wavelength is in the horizontal direction. Notice that higher peaks in the bottom frame match up with brighter lines in the top frame. Astronomers use spectra like these to learn all sorts of things about the Sun and stars.

5 Try it yourself.

The fold-out at the end of this booklet is an enlarged version of the bottom frame of Figure 3. This is part of an actual solar ultraviolet spectrum. The device that was used to obtain this spectrum is called the Solar Extreme-ultraviolet Rocket Telescope and Spectrograph, or SERTS for short. SERTS was built in the Laboratory for Astronomy and Solar Physics at Goddard Space Flight Center in Greenbelt, Maryland. The rocket that carried it above Earth's atmosphere was launched from White Sands Missile Range, New Mexico, in 1993. SERTS was above the atmosphere for about $6\frac{1}{2}$ minutes, and reached a maximum height of about 320 kilometers (200 miles) above the ground. It parachuted safely onto the desert in New Mexico, where it was picked up and returned to Goddard. SERTS also flew in 1989, 1991, 1995, 1996 and 1997, and will probably fly again in the future. Since building and launching devices like SERTS is much less expensive than building and launching Earth-orbiting satellites or interplanetary spacecraft, "sounding rockets" are often used to test new technology before the new technology is used on more expensive space missions. Several kinds of new technology were used in SERTS. Interested readers can visit the SERTS homepage on the World Wide Web at "http://orpheus.nascom.nasa.gov/serts/".

Table 1 gives a list of 39 ultraviolet emission lines that are found in a small portion of the Sun's spectrum. This table gives the wavelength in Å, the element, the number of electrons which have been lost by atoms of the given element, and the temperature in °C. (If the temperature were in °F, these numbers would be even larger.) Notice, for any particular element, that a higher temperature means a greater number of electrons are missing from the ions.

The emission lines in the fold-out look like narrow mountains. Some of them are very tall, and some of them are very short. The tallest ones are the brightest emission lines, and the shortest ones are the faintest. The bumps and wiggles toward the bottom of the figure are *noise*. Every scientific measurement contains noise of some sort. Sometimes the signal one is looking for is much stronger than the noise, and sometimes the noise can hide the signal. Here, for example, the noise limits our ability to see faint emission lines: emission lines that are so faint that they do not stand out above the noise are hard to find and even harder to measure.

Using Table 1 and the fold-out, can you say what are the two strongest emission lines in this part of the Sun's spectrum? How many other emission lines can you match with the lines listed in the table? What can you say about the Sun's composition, based upon these ultraviolet observations? What can you say about the Sun's temperature, based upon these observations? How can the Sun have more than one temperature at the same time?

6 Summary of main ideas.

• Light behaves like waves that travel through space. The distance between wave peaks is the wavelength of the light.

• Visible light, such as the colors of a rainbow, can be seen by human eyes. Other kinds of light, such as radio, microwave, infrared, ultraviolet, X-ray, and gamma ray, are invisible to human eyes.

• The different kinds of light all carry information about the Sun and stars to Earth.

• Earth's atmosphere absorbs much of the invisible kinds of light from the Sun and stars. Therefore, astronomers must use rockets to send special telescopes above Earth's air. These special telescopes can "see" light that is invisible to human eyes and that is blocked out by Earth's air.

• Every different kind of atom and every different kind of ion send out light at wavelengths that are special to that kind of atom or ion. Light at these wavelengths, known as emission lines, can be used like fingerprints to identify the atom or ion that sent out the light.

• Different ions of any element survive only in certain temperature ranges.

• When astronomers identify what atoms or ions exist on the Sun and stars from solar and stellar spectra, astronomers know both *what elements* are there and *what temperatures* are there.

• Besides providing information about the composition and temperatures of the Sun and stars, emission lines also provide information about densities, motions, magnetic fields, and other properties.

Information for Educators

After completing this lesson, students should be able to:

• define the terms "electromagnetic radiation," "spectrum," and "wavelength," as well as give examples of different types of radiation that are emitted by the Sun and other stars.
• explain the role of the Earth's atmosphere in protecting humans and other living organisms from the harmful types of radiation emitted by the Sun.
• describe the different types of information astronomers can obtain by studying light emitted from the Sun and other stars.
• identify elements present in a portion of the solar ultraviolet spectrum.

This activity should take approximately 90 minutes to complete.

Students should be provided with copies of the worksheet, the table on page 12, and the spectrum on the back cover.

This lesson supports the following National Science Education Standards for grades 5-8:

• **Content Standard A** – All students should develop the abilities necessary to do scientific inquiry and understandings about scientific inquiry.
• **Content Standard B** – All students should develop an understanding of the transfer of energy.
• **Content Standard C** – All students should develop an understanding of Earth in the solar system.

This lesson supports the following National Science Education Standards for grades 9-12:

• **Content Standard A** – All students should develop the abilities necessary to do scientific inquiry and understandings about scientific inquiry.
• **Content Standard B** – All students should develop an understanding of the structure of atoms, the structure and properties of matter, and the interactions of energy and matter.
• **Content Standard C** – All students should develop an understanding of energy within the Earth system and the origin and evolution of the universe.

Additional information can be found at the following web sites:
http://www.gsfc.nasa.gov
http://sohowww.nascom.nasa.gov
http://orpheus.nascom.nasa.gov/serts/

Name ______________________________ Date ______________________________

Analyzing Solar Spectra: Student Worksheet

Directions: Using Table 1 on page 12 and the spectrum at the end of this booklet, identify emission lines present in the solar spectrum. Can you identify 30 or more emission lines? Not all of the emission lines represent different elements. After you have finished, answer the questions below.

1. What are the two strongest emission lines in this part of the Sun's spectrum?

2. List the names of five elements you were able to identify. What can you say about the composition of the Sun based on your observations of this portion of the spectrum?

3. What can you say about the temperature of the Sun based on your observations of this portion of the spectrum? How does this compare with the temperature of the Earth?

4. Which portion of the electromagnetic spectrum can human eyes see? Which portions cannot be seen?

5. Many portions of the electromagnetic spectrum are harmful to living things. Why doesn't the Sun's radiation cause more damage to Earth?

6. What do astronomers need to do in order to study portions of the electromagnetic spectrum that are not observable from Earth?

7. Name two things that astronomers can learn about a star from studying its spectrum.

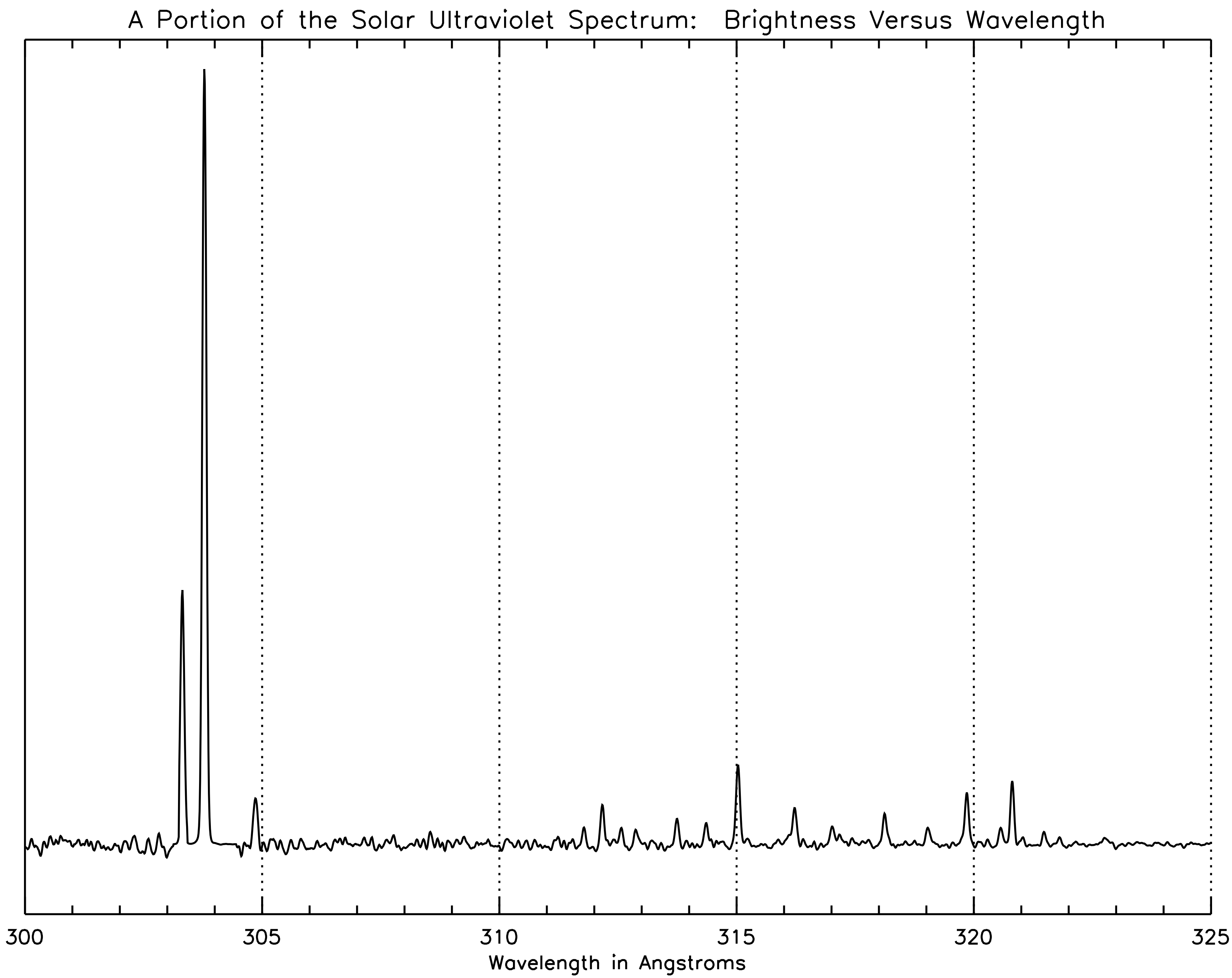
8. Match the terms on the left with the definitions on the right.

Angstrom	Energy produced by the Sun and stars that travels in waves.
Emission lines	A unit of length equal to one ten-billionth of a meter.
Light	The distance between two consecutive peaks of a wave.
Spectrum	Unique combinations of wavelengths in a spectrum used to identify elements.
Wavelength	Light separated into the wavelengts of which it is made.

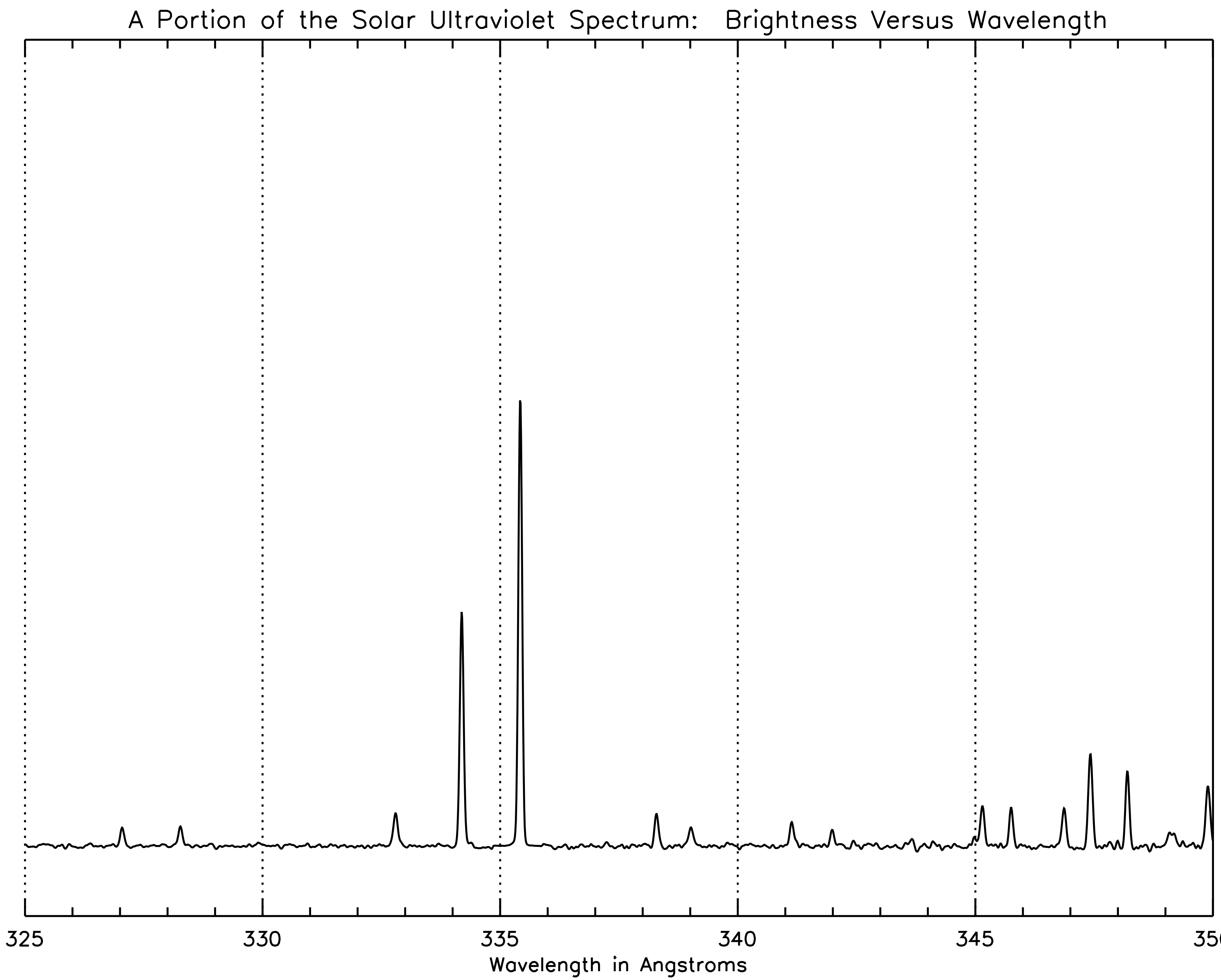
TABLE 1

Sample of Ultraviolet Emission Lines in a Solar Active Region Spectrum

No.	Element	Wavelength (Å)	Electrons Lost	Temperature (°C)
1	Silicon	303.317	10	1.6×10^6
2	Helium	303.782	1	4.7×10^4
3	Manganese	304.860	13	2.0×10^6
4	Iron	308.543	10	1.1×10^6
5	Iron	311.574	12	1.6×10^6
6	Magnesium	311.783	7	7.9×10^5
7	Iron	312.171	12	1.6×10^6
8	Iron	312.569	14	2.1×10^6
9	Iron	312.874	12	1.6×10^6
10	Magnesium	313.744	7	7.9×10^5
11	Silicon	314.358	7	7.9×10^5
12	Magnesium	315.029	7	7.9×10^5
13	Silicon	316.223	7	7.9×10^5
14	Magnesium	317.018	7	7.9×10^5
15	Iron	318.121	12	1.6×10^6
16	Magnesium	319.033	6	6.3×10^5
17	Silicon	319.852	7	7.9×10^5
18	Nickel	320.568	17	3.3×10^6
19	Iron	320.809	12	1.6×10^6
20	Iron	321.479	12	1.6×10^6
21	Iron	321.809	14	2.1×10^6
22	Iron	327.045	14	2.1×10^6
23	Chromium	328.270	12	1.6×10^6
24	Aluminum	332.799	9	1.3×10^6
25	Iron	334.191	13	1.9×10^6
26	Iron	335.418	15	2.7×10^6
27	Iron	338.290	11	1.4×10^6
28	Magnesium	339.014	7	7.9×10^5
29	Iron	341.136	10	1.1×10^6
30	Silicon	341.987	8	1.0×10^6
31	Silicon	344.974	8	1.0×10^6
32	Silicon	345.148	8	1.0×10^6
33	Iron	345.753	9	9.5×10^5
34	Iron	346.867	11	1.4×10^6
35	Silicon	347.421	9	1.3×10^6
36	Iron	347.823	16	4.0×10^6
37	Iron	348.199	12	1.6×10^6
38	Magnesium	349.124	5	4.0×10^5
39	Silicon	349.895	8	1.0×10^6



A Portion of the Solar Ultraviolet Spectrum: Brightness Versus Wavelength
300
305
310
315
320
325
Wavelength in Angstroms


A Portion of the Solar Ultraviolet Spectrum: Brightness Versus Wavelength
325
330
335
340
345
350
Wavelength in Angstroms